

# Investigation of the tunneling spectra in HgBr<sub>2</sub>-intercalated Bi-2212 single crystals below and above T<sub>c</sub>

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## Abstract

Interlayer tunneling spectroscopy measurements were performed on mesa arrays of Bi-2212 single crystals, intercalated with HgBr<sub>2</sub>. Tunneling conductances were obtained over a wide temperature range to examine the spectral features, especially the behavior of the quasiparticle peaks corresponding to superconducting energy gaps (SGs). Experimental spectra showed that gap-like features are still present even for the temperatures far above the transition temperature, T<sub>c</sub>. This evidence is consistent with the idea that the SG evolves into a pseudogap above T<sub>c</sub> for HgBr<sub>2</sub>-intercalated Bi-2212 single crystals.

*Key words:* High Temperature Superconductors, Intrinsic Josephson Junctions, Tunneling Spectroscopy, Pseudogap.  
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One of the puzzles for high-T<sub>c</sub> superconductors is the pseudogap (PG) that results in a depression of density of states at the Fermi level above T<sub>c</sub> [1]. Since tunneling spectroscopy can reveal the states near the Fermi level, it can give an insight about PG apart from superconducting gap (SG) in the quasiparticle excitation spectrum. The PG is clearly observed to exist in underdoped and optimally doped Bi-2212 single crystals. However, it is relatively hard to see these features above T<sub>c</sub> for heavily overdoped Bi-2212 specimens, since SG and PG are barely distinguishable for these crystals [2]. In this study, we report the tunneling measurements of overdoped, HgBr<sub>2</sub>-intercalated Bi-2212 crystals with bulk T<sub>c</sub> ~ 74 K. Although interlayer tunneling is a perfectly convenient technique for studying naturally occurring intrinsic Josephson junctions (IJJs) within copper oxide superconductors, excess Joule heating because of poor thermal conductivity of these materi-

als distorts the measured results substantially, e.g., possibly leading to a reduction in magnitude of SG. Intercalating inert HgBr<sub>2</sub> molecules between adjacent Bi-O layers increases the c-axis resistivity resulting in a hundred-fold suppression of the heat dissipation at a given voltage per junction [3].

Pristine Bi-2212 single crystals were grown by a floating zone technique and intercalation was accomplished by a vapor transport reaction between pure Bi-2212 crystals and HgBr<sub>2</sub> in air at 230 °C for 16 hours. After intercalation, T<sub>c</sub> for these crystals was measured to be 74 K, and it is generally thought that intercalated crystals are overdoped [4]. After additional heat treatments during mesa fabrication (150 °C for 1 hour in flowing air) these crystals may have further overdoped to an even lower T<sub>c</sub> (see below). For even greater minimization of heating effects, small mesa structures (10x10 μm<sup>2</sup> by ~50 nm height) were patterned on the crystal surface using photolithography and Ar ion milling [5]. For interlayer tunneling measurements, two conven-

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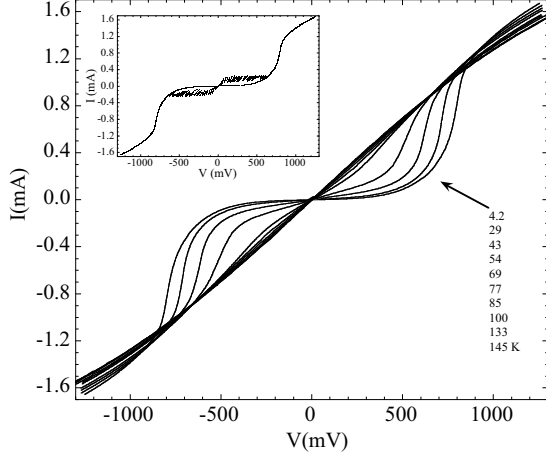


Fig. 1. Temperature dependence of I-V characteristics of a  $10 \times 10 \mu\text{m}^2$  mesa. The inset shows I-V characteristics with quasiparticle branches at 4.2 K.

tional contacts were made on two ends of the crystal while the third contact used a mechanically sharpened gold wire of  $100 \mu\text{m}$  in diameter, making a gentle contact on top of a particular mesa of the array. In order to see clearly the hysteretic quasiparticle branches in I-V characteristics, the current was cycled back and forth many times.

Figure 1 shows the temperature evolution of the current-voltage characteristics: for clarity, multiple quasiparticle branches (see IJJ stack data obtained at 4.2 K in inset) were removed to emphasize the behavior of the sum-gap branches with increasing temperature. We never observe ohmic behavior above  $T_c$  (even at 145 K) out to the modest voltages measured. The inset shows 30 individual tunneling junction resistive branches for this mesa with a spacing of  $\sim 24 \text{ mV}$  each.

The tunneling conductances, i.e. the numerical derivatives of I-V curves shown in Fig. 1, are displayed in Figs. 2(a) and (b) at various temperatures from 4.2 K to 145 K. The quasiparticle peaks decrease in height and smear out with increasing temperature. However, the data for 77 to 112 K still show a broad gap-like quasiparticle peak structure that may be taken as evidence of a pseudogap in  $\text{HgBr}_2$  doped Bi-2212 samples. This feature can give an insight about the emergence of a pseudogap below 112 K. Above 145 K the conductivity monotonically decreases with absolute voltage. The inset of Fig. 2(a) shows the gap voltage obtained from the peak position,  $V_p$ , vs. temperature from which a  $T_c$  of  $\sim 69 \text{ K}$  can be inferred. From the same plot one can judge the compatibility of the experimental data

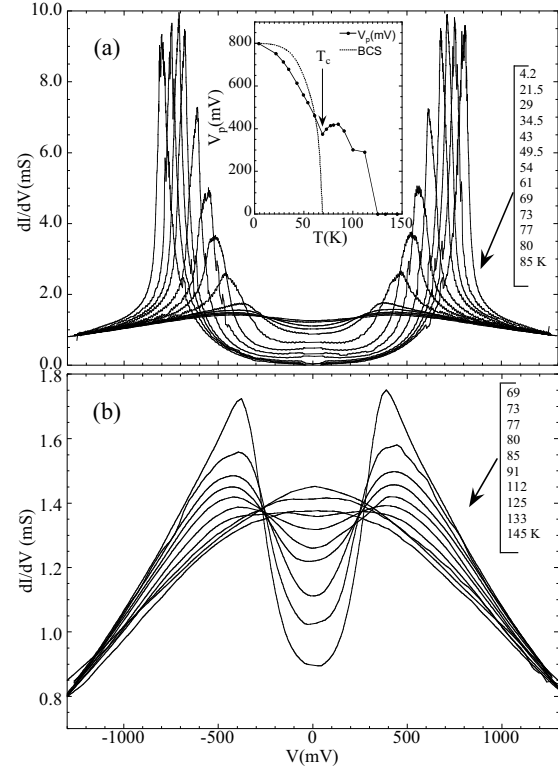


Fig. 2. Temperature dependence of  $dI/dV$ -V characteristics of a  $10 \times 10 \mu\text{m}^2$  mesa. (a)  $T=4.2\text{--}85 \text{ K}$ , (b)  $T=69\text{--}145 \text{ K}$ . The inset shows evolution of sumgap peaks with temperature.

to the BCS temperature dependence. Below  $T_c$ , the voltage drops much more rapidly with increasing temperature in the experimental data, and is never zero at  $T_c$ . There is an upward deviation beyond  $T_c$  that may be a sign of hybridization of superconducting peak with the pseudogap [6]. In conclusion, our interlayer tunneling measurements of  $\text{HgBr}_2$  intercalated Bi-2212 single crystals endorse the existence of PG above  $T_c \sim 69 \text{ K}$  that we have observed up to 112 K.

## References

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